Definition and Synergies of Cognitive Infocommunications

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Abstract: In this paper, we provide the finalized definition of Cognitive Infocommunications (CogInfoCom). Following the definition, we briefly describe the scope and goals of CogInfoCom, and discuss the common interests between CogInfoCom and the various research disciplines which contribute to this new field in a synergistic way.

Keywords: Cognitive Infocommunications, CogInfoCom channels

1 Introduction

The first working definition of Cognitive Infocommunications (CogInfoCom) appeared in [4]. The early definition was finalized through the panel discussions of the startup committee (see the Acknowledgements section) at the First International Workshop on Cognitive Infocommunications in 2010.

In this paper, we provide the finalized definition of CogInfoCom as well as a discussion on its scope and goals. In the second half of the paper, we provide an overview of a number of fields that are related to CogInfoCom in a way that is expected to give rise to unique synergies in the near future. The paper is structured as follows. In section 2, we provide the definition of CogInfoCom. In section 3, we describe the background of CogInfoCom from a research historical perspective. Finally, in section 4, we describe how CogInfoCom is related to other fields which contribute to it in a synergistic way.

We would like to thank the area chairs of the annually held CogInfoCom conference for their significant contributions to the definition of CogInfoCom.

2 Definition of CogInfoCom

Cognitive infocommunications (CogInfoCom) investigates the link between the research areas of infocommunications and cognitive sciences, as well as the various engineering applications which have emerged as a synergic combination of these sciences.

The primary goal of CogInfoCom is to provide a systematic view of how cognitive processes can co-evolve with infocommunications devices so that the capabilities of the human brain may not only be extended through these devices, irrespective of geographical distance, but may also interact with the capabilities of any artificially cognitive system. This merging and extension of cognitive capabilities is targeted towards engineering applications in which artificial and/or natural cognitive systems are enabled to work together more effectively.

Two important dimensions of cognitive infocommunications are defined: the mode of communication, and the type of communication. The **mode of communication** refers to the actors at the two endpoints of communication:

- **Intra-cognitive communication**: information transfer occurs between two cognitive beings with equivalent cognitive capabilities (e.g., between two humans).
- **Inter-cognitive communication**: information transfer occurs between two cognitive beings with different cognitive capabilities (e.g., between a human and an artificially cognitive system).

The **type of communication** refers to the type of information that is conveyed between the two communicating entities, and the way in which this is done:

- **Sensor-sharing communication**: entities on both ends use the same sensory modality to perceive the communicated information.
- **Sensor-bridging communication**: sensory information obtained or experienced by each of the entities is not only transmitted, but also transformed to an appropriate and different sensory modality.
- **Representation-sharing communication**: the same information representation is used on both ends to communicate information.

- **Representation-bridging communication**: sensory information transferred to the receiver entity is filtered and/or adapted so that a different information representation is used on the two ends.

Remarks

1. CogInfoCom views any kind of hardware or software component that collects and stores information and allows users to interact with this information as an infocommunication system. Depending on the complexity required for an infocommunication system to obtain this information (e.g., through sensing or inference), it is said that the system can have various levels of cognitive capabilities. Hence, we may speak of *artificially cognitive systems*, as well as the infocommunication between artificially cognitive systems and humans.

2. A sensor-sharing application of CogInfoCom brings novelty to traditional infocommunications in the sense that it can convey any kind of signal normally perceptible through the actor's senses to the other end of the communication line. The transferred information may describe not only the actor involved in the communication, but also the environment in which the actor is located. The key determinant of sensor-sharing communication is that the same sensory modality is used to perceive the sensory information on both ends of the infocommunications line.

3. Sensor bridging can be taken to mean not only the way in which the information is conveyed (i.e., by changing sensory modality), but also the kind of information that is conveyed. Whenever the transferred information type is imperceptible to the receiving actor due to the lack of an appropriate sensory modality (e.g., because its cognitive system is incompatible with the information type) the communication of information will necessarily occur through sensor bridging.

4. A CogInfoCom application can be regarded as an instance of representation-sharing even if it bridges between different sensors. For example, if text is conveyed to a blind person using Braille writing, the tactile sensory modality is used instead of vision, but the representation still consists of a linear succession of textual elements which represent individual characters in the alphabet. Similarly, although Morse code bridges between the visual and auditory sensory systems (i.e., what is normally read is heard), the representation it uses is a linear, alphabet-based representation. In more complex cases, it is up to psychologists and neuroscientists to determine whether two representations can be said to compatible or not.

5. By the same token, a CogInfoCom application can be considered as representation-bridging even if it is sensor-sharing. Based on this and the previous item, it is clear that the concepts of sensor sharing and bridging, and representation sharing and bridging are orthogonal to each other.

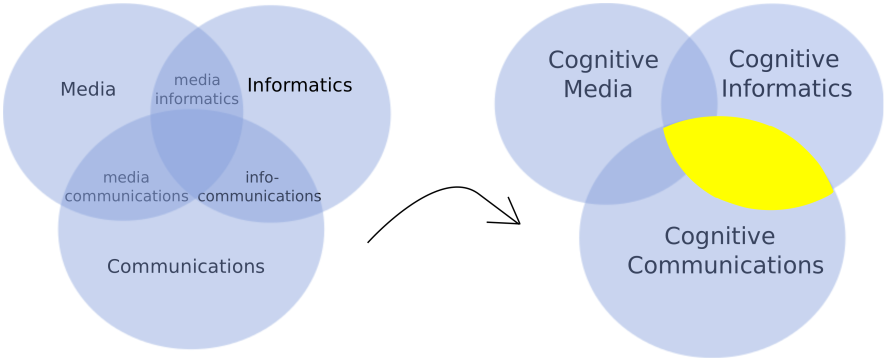


Figure 1
The three fields of media, informatics and communications originally created separate theories, but are gradually merging together today. CogInfoCom is situated in the region between cognitive informatics and cognitive communications

3 Research Historical View of CogInfoCom

It is useful to consider the research historical aspects which have led to the creation of CogInfoCom. Traditionally, the research fields of *informatics*, *media*, and *communications* were distinct research areas, treated by researchers from significantly different backgrounds. As a synthesis between pairs of these 3 disciplines, the fields of *infocommunications*, *media informatics* and *media communications* emerged in the latter half of the 20th century. The past evolution of these disciplines points towards their convergence in the near future, given that modern network services aim to provide a more holistic user experience, which presupposes achievements from these different fields [29, 35].

Parallel to these developments, with the enormous growth in scope and generality of cognitive sciences in the past few decades, the new fields of *cognitive media* [31, 23], *cognitive informatics* [49, 48, 44] and *cognitive communications* [34, 16] are gradually emerging. These fields have also either fully made their way, or are steadily on their way into standard university curricula. In a way analogous to the evolution of infocommunications, media informatics and media communications, we are seeing more and more examples of research achievements which can be categorized as results in *cognitive infocommunications*, *cognitive media informatics* and *cognitive media communications*, even if – as of yet – these fields are not always clearly defined (Figure 1).

4 Synergistic Relationship between CogInfoCom and Other Fields

In a large part of CogInfoCom research, the goal is to create CogInfoCom channels through which artificially cognitive systems can communicate with each other and with natural cognitive systems in a way that appeals to their respective cognitive capabilities.

In this respect, CogInfoCom has common interests with other fields such as human-computer interaction (HCI), multimodal interaction, affective computing and sensory substitution, and many others. These fields all focus on novel forms of communication between humans and machines. However, a departure from these fields is often necessary for CogInfoCom, primarily because the types of information that must be communicated between artificial systems and users may not always be directly perceptible by the available sensory and cognitive subsystems (hence the need for sensor-bridging). In other cases, the transformation of information from one sensory modality to another (sensor-bridging) and from one representation to another (representation-bridging) may provide more effective interaction between the communicating systems.

In this section, we provide a brief overview of the relationship between CogInfoCom and various other fields in computing and cognitive sciences (i.e., affective computing, augmented cognition, body area networks, brain-computer interfaces, cognitive informatics, cognitive linguistics, future internet, HCI & multimodal interaction, infocommunications, sensory substitution, and virtual reality). It is important to emphasize that all of the fields listed here have their own motivations and their own set of methodologies. Thus, we focus only on those aspects which represent opportunities for synergy with CogInfoCom, either in the CogInfoCom interface or in the artificially cognitive engine that motivates the communication of artificially cognitive systems (for more details on this duality, we refer the reader to [27]).

4.1 Affective Computing

Affective computing is a research direction first proposed by R. Picard at MIT in the late 1990s that aspires to bring the communication between humans and machines to a new level by enabling machines to perceive and exhibit human-like qualities (e.g., facial expressions, bodily gestures and vocal qualities) during communication [28].

A common goal of affective computing systems is to simulate empathy towards the user. Especially in those cases where this is achieved by means of sensing human psychological and emotional states, affective computing systems can be viewed as artificially cognitive systems. If such systems are used for infocommunication purposes (i.e., as a form of inter-cognitive infocommunication), it is clear that results in affective computing can contribute in significant ways to CogInfoCom.

4.2 Augmented Cognition

Augmented cognition (AugCog) is a relatively new field of science which aims to extend the user's abilities via computational technologies, while taking into account cognitive aspects such as limitations in attention, memory and learning capabilities [36]. The foundations of AugCog were laid down by D. Schmorrow and his colleagues as part of a DARPA program in the first decade of the 21^{st} century [36]. The 1^{st} International Conference on Augmented Cognition was held in 2005.

In many cases, AugCog deals with specific types of systems in which human users communicate with information systems in a closed loop [13]. The goal of AugCog is to allow information systems to be "*calibrated and tailored to meet the varying human information processing strengths and weaknesses of any individual*"[1], mainly based on neuroscientific, psychological and ergonomic considerations. Thus, augmented cognition can be seen as a research area that provides ways to feed augmented information to the human neurobiological system (as opposed to body area networks, which focus on the extraction of information from the human body).

If this kind of augmented information transfer occurs specifically between infocommunication systems and humans, then augmented cognition has much to offer for CogInfoCom. Further, AugCog and CogInfoCom can be expected to have a synergic relationship in application areas such as virtual realities and the Future Internet, where unique emphasis is laid on the communication between humans and abstract, immaterial entities which are not compatible with the usual human cognitive capabilities.

4.3 Body Area Networks

Body area networks (BANs), or body sensor networks (BSNs) are specialized applications of wireless sensor networks in which a network of sensors, either attached to or implanted in the human body communicate physiological information to a central server [7]. The predecessors of BANs were referred to as Personal Area Networks (PANs), which were first developed around 1995 (see e.g. [52] for an example from MIT). The term BSN was coined at the start of the 21^{st} century by G-Z. Yang at Imperial College London to refer to those technologies for communication which operate near and around the human body [2].

Body area networks can encompass a large variety of different kinds of interactions between the physical sensors they use and the human biological and cognitive system. Thus, interaction can be based on deeply implanted active sensor systems on one end of the spectrum, or it can be based on passive external sensor measurements on the other end of the spectrum. It is clear, however, that if augmented cognition

[1] The quote is from http://www.augmentedcognition.org

[2] The official page of body sensor networks which confirms this can be found at http://ubimon.doc.ic.ac.uk/bsn

is viewed as dealing with how to feed augmented information to the user, then body area networks can be seen as dealing with how to extract information from the human biological and cognitive system. Body area networks can significantly enrich CogInfoCom applications by feeding specific aspects of the human cognitive state through infocommunication devices.

4.4 Brain-Computer Interfaces

Brain Computer Interfaces (BCI), sometimes also referred to as Brain Machine Interfaces (BMI), is a research field that deals with the creation of direct communication pathways between the brain and a machine [45]. Research on BCI began in the early 1970s at UCLA, and was funded by the U.S. government through DARPA [45, 46].

Although there is some similarity between BCI and body area networks, these two research areas are significantly different from at least four aspects:

- Brain-computer interfaces focus on the brain, while body sensor networks focus on the whole body
- Brain-computer interfaces generally use a single structure for sensing and actuating as opposed to a distributed set of sensors
- Communication through a brain-computer interface is in many cases bi-directional (as opposed to the uni-directional, sensing functionlity of body sensor networks)
- Due to the fact that brain-computer interfaces are generally used for direct communication between a brain and a machine, the application in which the interface is used imposes stronger constraints on the interface. In contrast, the design of body area networks in many cases does not take into consideration so many aspects of a target application.

Results in BCI research are culminating in the appearance of both invasive and non-invasive brain-computer interfaces in medical (e.g., Dobelle's vision implant inspired by research described in [9, 10], and the BrainGate interface [17]) as well as gaming applications (e.g. the products of Emotiv Systems and OCZ Technology).

From the point of view of CogInfoCom, such commercially available devices can be useful for direct communication in inter-cognitive CogInfoCom applications. More generally speaking, the relationship between BCI and CoginfoCom can be fruitful because BCI investigates scenarios in which neurons and electronic devices come into direct contact with each other. Hence, synergy between BCI and CogInfoCom arises when informatics, the neurosciences and infocommunications meet at a direct, low level.

4.5 Cognitive Informatics

Cognitive informatics (CI) is a research field which was created in the early 21st century (the first international conference in the field was organized by Y. Wang in 2002) [47, 49]. There are several definitions of CI available on the Internet. The definition on the webpage of Pacific Northwest Natonal Laboratory (which is a research institute funded by the U.S. Dept. of Energy) states that Cognitive Informatics is the *"multidisciplinary study of cognition and information sciences, which investigates human information processing mechanisms and processes and their engineering applications in computing"*[3].

One of the main purposes of CI is to investigate the internal information storing and processing mechanisms in natural intelligent systems such as the human brain. Much like CogInfoCom, CI also aims to create numerically tractable models which are well grounded from an information theoretical point of view, and are applicable to engineering systems. The key difference between CI and CogInfoCom is that while the results of CI largely converge towards and support the creation of artificially cognitive systems, the goal of CogInfoCom is to enable these systems to communicate with each other and their users efficiently.

Thus, CogInfoCom builds on a large part of results in CI, in that it deals with the communication space between the human cognitive system and other natural or artificially cognitive systems.

4.6 Cognitive Linguistics

CogInfoCom can be approached from a cognitive linguistics perspective. Cognitive linguistics views language as a form of communication that is embodied and situated in a specific environment. In other words, the cognitive linguistic view maintains that language is an emergent cognitive capability that is inseparably intertwined with the way in which we interact with the environment [8]. More specifically, cognitive linguists believe that patterns called image schemas are formed whenever we engage in sensorimotor interaction with the environment, and that these schemas are embedded into our cognition so deeply that they have an effect on the way we think (and speak), even about abstract, nonphysical entities [19].

If an artificially cognitive system can communicate information to the user through synthesized speech and the syntax and patterns used for this speech-based communication are grounded in cognitive linguistics research, then the communication of the artificially cognitive system is clearly related to both CogInfoCom and cognitive linguistics.

[3] http://www.pnl.gov/coginformatics

4.7 Future Internet

Future Internet is a key research direction in modern computing that deals with the theoretical and practical aspects of creating networks though which users could interact not only with computers, but also with everyday objects and abstract computational capabilities [41].

Two major directions in Future Internet research are the **Internet of Things** and **3D Internet**. The Internet of Things deals with the physical integration of everyday objects and their unique capabilities on the Internet. A recent overview of key architectural designs and applications can be found in [42]. 3D Internet, which is a more recent development, focuses on the growing expectation of users for "*high-quality 3D imagery and immersive online experience*" [20]. 3D Internet is a natural part of the Future Internet concept, because with the appearance of everyday objects on the Internet, users will still expect to be able to handle them in the same ways as they do in the physical world.

A consequence of both of these research directions is that users are expected to be able to communicate with things (i.e. everyday objects) on the Internet, and also to collaborate with them in ways that depend only on the (artificially cognitive) capabilities of the objects. Because the objects, as viewed from the Internet, can be a combination of physical and virtual components, collaboration in this case can be regarded as augmented collaboration. In this regard, CogInfoCom has common interests with Future Internet in terms of deciding what type of information to communicate, and *how* to make the communication of the information more natural to the user.

4.8 Human-Computer Interaction and Multimodal Interaction

There are several aspects of HCI and Multimodal Interaction which should ideally be considered in CogInfoCom applications. We summarize these aspects as follows:

- **negative effects of reduced resolution** – There are convincing studies which show that it is better to use different modalities than the ones that are normally used for a given task when the resolution of data flow is reduced through the normal modality. For example, according to Verner and Okamura, providing force feedback that is reduced in degrees of freedom can result in the destabilization of teleoperation systems [43]. More specifically, in applications such as remote knot-tying in telesurgery, it was shown that the forces applied by the telesurgeon were closer to the normal, manual case when auditory and graphical displays were used instead of direct, but reduced-precision force feedback [22]. A specific solution to vibrotaction-based force feedback was proposed by Galambos [14].
- **multi-sensory integration** – There is extensive proof in the literature that different sensory channels are not independent of each other. While contradicting

information from various senses can cause confusion, simulation sickness or other discomfort, illusions in which stimulation in one sensory channel leads to the illusion of stimulation in another sensory channel can be very powerful in virtual and/or remote teloperation [6]. The ability of human cognition to integrate experience from various sensory channels is referred to as intermodal (or intersensory) integration.

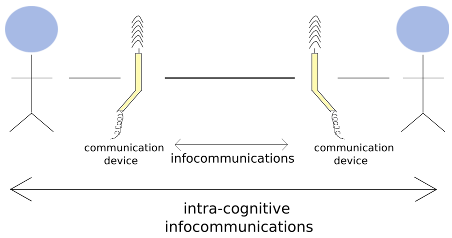
- **cross-effects between sensory modalities** – Researchers have long ago discovered that the impression that different sensory modalities are independent of each other is "*more illusory than real*" [40]. Thus, when designing feedback strategies in teleoperation systems, care must be taken so that the operator is not overloaded with sensory information. Although multi-sensory information can help in many cases, its effects can also be counterproductive if the user is burdened with too much information [24, 51]. The question as to whether multi-sensory feedback is productive or not has much to do with the degree of redundancy in the information that is presented [24, 33]. However, Biocca et al in [6, 5] also suggest that it is possible for one sensory modality to yield realistic sensations normally perceived through another modality, while another sensory modality gives no contribution to realistic sensations, but significantly increases the user's sense of telepresence.

- **sensory dominance** – another key point of interest when designing multimodal interfaces is how the various sensory modalities relate to one another in terms of importance to human cognition. This is referred to as the question of sensory dominance. There have been a number of studies which show that vision dominates haptic touch and audition [38, 50, 26, 15], but it was also shown that relationships of dominance can become more complex if more than two modalities are under stimulation at the same time [15].

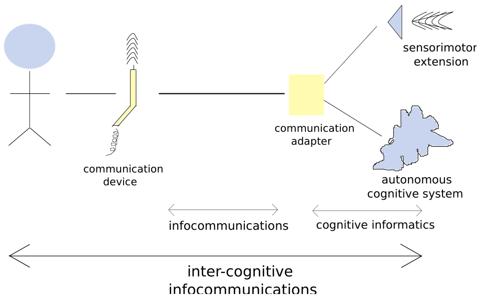
4.9 Infocommunications

With the rapid evolution and growing complexity of infocommunication devices (e.g., smartphones and tablets), it is becoming necessary to consider the communication which occurs between the human user and the device. As the electronics industry, together with users, develops new modes of interaction, the border between traditional infocommunications and CogInfoCom is gradually becoming less clear-cut. As a result, infocommunication devices of the future are expected to perform a larger variety of sensing and inference tasks, and are expected to interpret and transform information rather than merely transmitting raw, uninterpreted data.

A conceptual view of how CogInfoCom builds on cognitive informatics and infocommunications can be seen in Figure 2.



(a) Intra-cognitive infocommunications



(b) Inter-cognitive infocommunications

Figure 2
Cognitive informatics and infocommunications view of CogInfoCom. Figure 2(a) shows a case of intra-cognitive infocommunications, and demonstrates that while traditional infocommunications deals with the distance-bridging transfer of raw data (not interpreted by any cognitive system), cognitive infocommunications deals with the endpoint-to-endpoint communication of information. Figure 2(b) shows a case of inter-cognitive infocommunications, when two cognitive systems with different cognitive capabilities are communicating with each other. In this case, autonomous cognitive systems as well as remote sensors (sensorimotor extensions, as described in the definition of the sensorbridging communication type) require the use of a communication adapter, while biological cognitive systems use traditional telecommunications devices

4.10 Sensory Substitution

Sensory substitution is a research direction that provides room for synergy with sensor-bridging CogInfoCom. The basic idea behind sensory substitution, and its utility was first described by Bach-y-Rita and his colleagues, who, in one of their more recent works, define sensory substitution as "*the use of one human sense to receive information normally received by another sense*" [3].

There are at least two aspects in which sensory substitution leaves room for future research. The first aspect, highlighted by Auvray and Myin in [2] is the question of whether sensory substitution can truly be regarded as substitution. Some have argued that despite sensory substitution, the new stimuli should still be regarded as generating percepts from the original, substituted modality (this is known as the *def-*

erence thesis, e.g. as in [18]). Others have argued the opposite, maintaining that the new, substituting modality dominates the substituted modality, and that the stimuli should be regarded as generating percepts in the substituting modality (this is known as the *dominance thesis*, e.g. as in [30]). The key novelty of Auvray and Myin's investigations is that they demonstrate – using concepts from the psychophysics and psychology of sensory modalities (e.g., sensory organs, qualitative experience, behavioral experience, dedication and sensorimotor equivalence [21, 25]) – that the modality used after sensory substitution is in fact a completely new one, which is different from both the substituting and the substituted modalities.

The second aspect is the realization that it may be useful to broaden the scope of sensory substitution, at least in engineering systems, was also recognized by Bach-y-Rita and his colleagues. This was eloquently highlighted as follows [3]:

> *However, in the context of mediated reality systems, which may incorporate multiple modalities of both sensing and display, the use of one sense [...] to display information normally acquired via another human sense [...] or alternatively via a 'non-natural' sense such as sonar ranging, could be considered to be a form of sensory augmentation (i.e., addition of information to an existing sensory channel). [...] We therefore suggest that, at least in multimodality systems, new nomenclature may be needed to independently specify (a) the source of the information (type of environmental sensor, or virtual model); (b) the type of human information display (visual, auditory, tactual, etc.); and finally (c) the role of the information (substitutive or augmentative), all of which may play a role in reality mediation.*

In this statement, Bach-y-Rita, Tyler and Kaczmarek clearly demonstrate that although sensory substitution is sufficient in describing many applications, it could be valuable to broaden the scope of sensory substitution so that it can be used to describe many forms of communication between humans and machines, even if the source or destination of the communication cannot be described using the traditional senses of the human nervous system. Such a position seems viable, primarily because the types of information that must be communicated between artificial systems and the user may not always be directly perceptible by the available sensory and cognitive subsystems (hence the need for sensor-bridging). In other cases, the transformation of information from one sensory modality to another (sensor-bridging) and from one representation to another (representation-bridging) may provide more effective interaction between the user and the system.

It is clear that the terminology used in CogInfoCom is in many respects a reflection on the suggestion of Bach-y-Rita and his colleagues. The distinction between intra-cognitive and inter-cognitive forms of cognitive infocommunication reflects their first criterion regarding the new terminology (i.e., regarding the source of the information). The distinction between sensor-sharing and sensor-bridging answers the proposition to distinguish between different types of human information display. Finally, the concepts of representation-sharing and representation-bridging are some-what related to the third point, namely to the question of whether the transferred information is substituted or augmented.

4.11 Virtual Reality Research

In everyday human-machine interaction, both the human and the machine are located in the same physical space and thus users can rely on their natural cognitive systems to communicate with the machine. In contrast, when 3D virtualization comes into play, the human is no longer in direct connection with the machine; instead, he/she must communicate with its virtual representation [32, 39]. Thus, the problem of human-machine interaction is transformed into a problem of human-virtual machine interaction. CogInfoCom and virtual reality research can have fruitful synergies in the following aspects of human-virtual machine interaction:

- The natural communication capabilities of the human become limited due to the restricted interface provided by the virtual representation of the machine (for instance, while the senses of vision and audition still receive considerable amount of information, the tactile and olfactory senses are almost completely restricted in virtual environments, i.e. it is usually not possible to touch or smell the virtual representation of a machine). For this reason, it becomes necessary to develop a virtual cognitive system which can extend the natural one so as to allow the human to effectively communicate with the virtual representation. In this extended scenario, the virtual representation of the remote system can be viewed as an infocommunication system through which the remote system communicates with the user.
- *Situation awareness* (also commonly referred to as telepresence) is a measure of the degree to which the user feels present in the remote or virtual environment [37, 12]. In an early work on the subject, Sheridan outlines 3 key components of telepresence: the extent of sensory information, the control of relation of sensors to the environment, and the ability to modify the physical environment [38]. *Encumberment* is a term used often in the literature to describe the extent to which the user is burdened with having to wear various kinds of sensors in order to interact with a system [11, 1]. It is natural to try to reduce encumberment in virtual environments, however, doing this conflicts the goal of increased situation awareness.

CogInfoCom has common interests with virtual reality research along these two aspects. One of the primary goals of CogInfoCom with respect to these aspects is to be able to augment the sensory capabilities of both the human user and the artificially cognitive system so that they can communicate with each other at a higher level, thus alleviating the difficulties of human-virtual machine interaction and the conflicting goals of situation awareness and unencumberment.

Conclusions

In this paper, we provided the finalized definition of Cognitive Infocommunications (CogInfoCom). Following the definition, we briefly described the scope and goals of CogInfoCom, as well as its research historical background. In the second half of the paper, we discussed the common interests between CogInfoCom and a number of research disciplines which contribute to this new field in a synergistic way.

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